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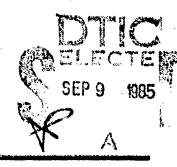
July 1985

IN SITU DETERMINATION OF BUTYLTIN RELEASE RATES FROM ANTIFOULING COATINGS ON NAVY TEST SHIPS

S. H. Lieberman Naval Ocean Systems Center

V. Homer Computer Sciences Corporation

P. F. Seligman Naval Ocean Systems Center





Naval Ocean Systems Center

San Diego, California 92152-5000

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NAVAL OCEAN SYSTEMS CENTER SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

F. M. PESTORIUS, CAPT, USN

Commende

R.M. HILLYER

Technical Director

ADMINISTRATIVE INFORMATION

This project was authorized by W. Stoffel of the David Taylor Naval Shir Research and Development Center, Energy Office (Code 2759). The work was sponsored by the Chief of Naval Material (MAT 08E) (now Office of Naval Technology (ONT 07E)), under work request NU0167-84-WR4-0449. Work on this project was accomplished by the Environmental Sciences Division (Code 52) of the Naval Ocean Systems Center, with contractual assistance for analytical services from Computer Sciences Corporation, San Diego, and the Research Corporation of the University of Hawaii. Additional support for methods development was provided by work request N00167-84-WR-4-0028.

Released by P. F. Seligman, Head Marine Environment Branch Under authority of S. Yamamoto, Head Environmental Sciences Division

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This report presents the results of a series of in situ leach rate measurements on the hulls of three Navy test ships coated with antifouling paints containing tributyltin oxide. The flux of tributyltin from six different organotin coatings was determined under actual environmental conditions using the in situ leach rate measurement system developed at the Naval Ocean Systems Center. Values ranged from 0.18 to 3.2 µg/cm²/day.								
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EXECUTIVE SUMMARY

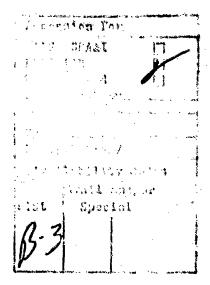
OBJECTIVE

Determine in situ leach rates of tributyltin on the hulls of three Navy test ships coated with different formulations of antifouling paints containing tributyltin oxide.

RESULTS

Measured leach rates ranged from a high of 3.2 μ g TBT/cm²/day. The SPC-254 coating on the USS CORAL SEA showed the lowest leach rate with a mean value of 0.24 \pm 0.05 μ g TBT/cm²/day. The OMP M5211S coating on the USS MEYERKORD showed the highest value (3.2 μ g TBT/cm²/day).

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INTRODUCTION

The Navy is considering fleet implementation of organotin antifouling (AF) coatings. Realistic estimates of organotin flux from the fleet, preferably under actual environmental conditions, are required to assess the potential environmental impact of these coatings. This report presents the results of a series of in situ measurements made on the hulls of three Navy test ships coated with AF paints containing tributyltin oxide. Measurements were made using the in situ leach rate measurement system (ISLRMS), which was developed at the Naval Ocean Systems Center (NOSC) under the sponsorship of the Energy Office of the David Taylor Naval Ship Research and Development Center (NAVMAT ORE). The ISLRMS was originally designed for measuring the biocide flux from copper AF coatings (NOSC Patent No. 4,375,451) and, subsequently, was modified for measuring organotin release rates. Leach rate values are reported for the commercial ablative AF paint systems, ABC-2, SPC-254, and SPC-4 and also the Navy-formulated organometallic polymer (OMP) AF paints: OMP M5211F, OMP M5211S, and OMP 58S. For comparison, the organotin emission rate from two panels coated with ABC-2 was also determined using an independent laboratory procedure,

METHODS

IN SITU LEACH RATE MEASUREMENTS

The apparatus used for measurement of in situ organotin release rates is shown schematically in Figure 1. The system consists of a 12-inch diameter polycarbonate dome connected by two 50-foot lengths of 1/4-inch (inside diameter) Teflon (FEP) tubing to a peristaltic pump operated from the diving platform. Additional lengths of tubing can be added if required. An in-line vacuum gauge is used to monitor the pressure within the system, and a three-way valve is used in conjunction with the pump to collect water samples from the system.

Materials used to fabricate the system were selected based on their low adsorptivity towards tributyltin (Homer and Seligman, 1984). The dome was formed from a 1/4-inch-thick sheet of polycarbonate, and the manifolds were machined from polycarbonate stock. Viton tubing was used in the pump head and for all manifold-dome connections.

The dome (shown in Figure 2) is fitted with a double-edged gasket used to form a seal against the ship's hull. Details of the manifold system and the inlet and outlet ports are shown in Figures 3 and 4, which show top and bottom views of the dome respectively. The peristaltic pump is used to draw water from the manifold connected to six outlet ports distributed around the perimeter of the dome. The return flow enters the dome through a manifold connected to four inlet ports equipped with directional nozzles. Dye studies conducted using a prototype of the same configuration showed this arrangement produced uniform gentle mixing of the volume of seawater within the dome.

The procedure for determining in situ leach rates is as follows: the domes and attached tubing are placed in the water at the test site, and water is circulated through the system for approximately 10 minutes. This removes any water left in the system from previous measurements and equilibrates the system with the ambient water. Divers then position the dome's double-edged

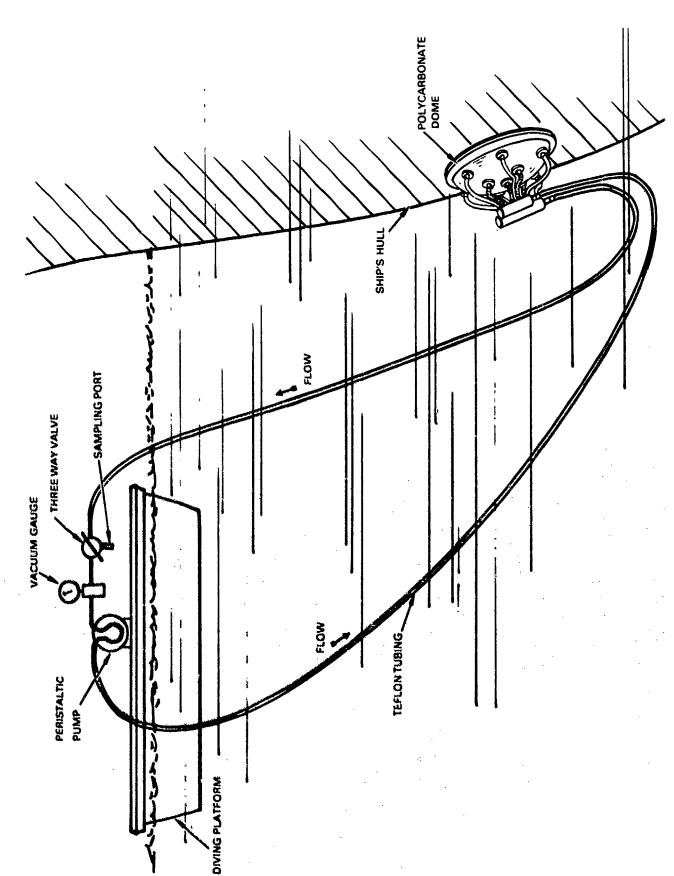


Figure 1. Schematic of in situ leach rate measurement system.

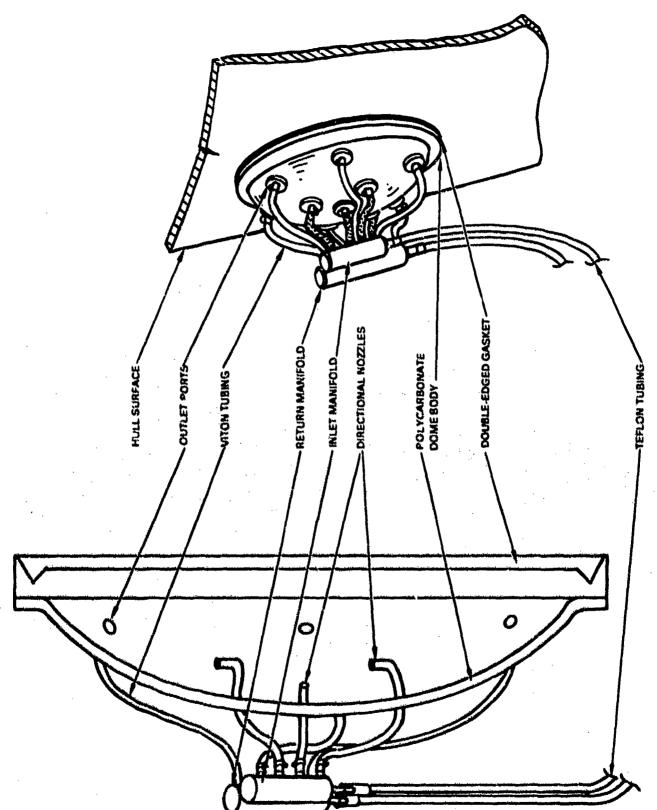


Figure 2. Schematic of polycarbonate dome and manifold system.

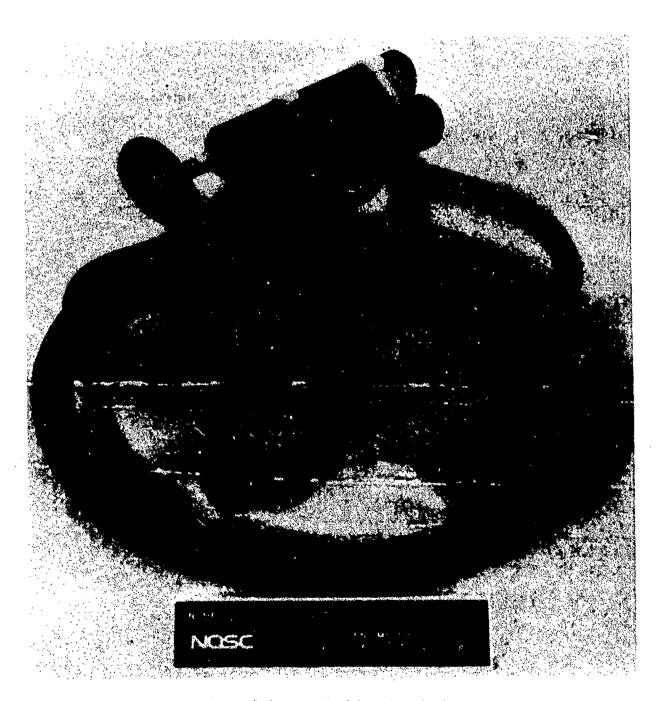


Figure 3. Photograph of dome (top view).

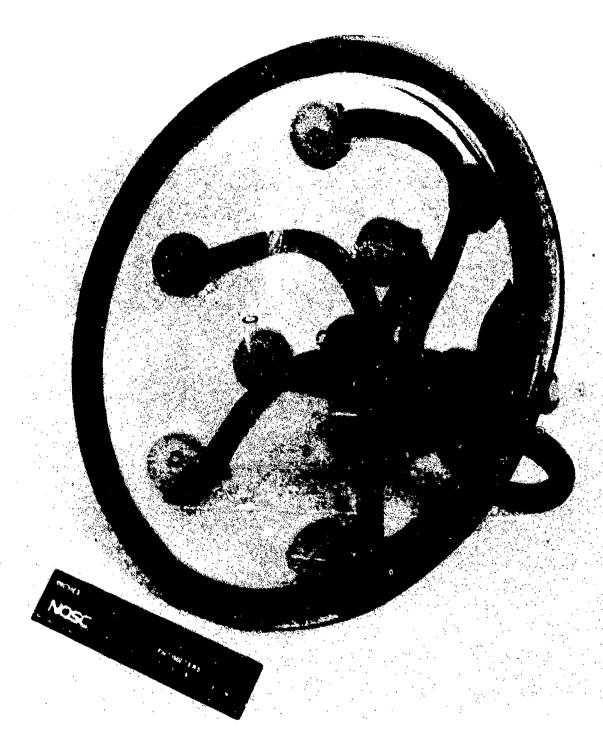


Figure 4. Photograph of dome (bottom view) showing double-edged gasket.

gasket against the hull at a selected sampling location on the hull. A volume of water is then pumped from the closed system until a sufficient vacuum is established to hold the dome in place. The actual vacuum is monitored using an in-line vacuum gauge. The volume of water in the system is recirculated using a flow rate maintained at approximately 525 ml/min. Ten to twenty ml samples are withdrawn from the system every 10 minutes, and the samples are placed on ice until they can be transferred to a refrigerator. Normally, three color-coded (red, yellow, and green) dome systems are used at each sampling site to produce triplicate sample sets.

LABORATORY LEACH RATE DETERMINATIONS

Two steel panels coated with ABC-2 were used to make independent leach rate determinations. One of the panels was removed from the USS KITTY HAWK after 25 months of exposure, and the second test panel had been exposed to San Diego Bay water for 12 months. Determinations were conducted in polycarbonate aquaria filled with 14 L of unfiltered Point Loma seawater and immersed in a flow-through seawater trough to control temperature during the experiment. After a baseline sample was collected, a panel was immersed in each aquarium, and constant gentle circulation was maintained using three air stones in each tank. A sample was removed with a 10-ml volumetric pipette every 10 minutes for 1 hour.

ORGANOTIN ANALYSES

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The organotin concentration in each sample collected from either the in situ system or the laboratory system was determined using graphite furnace atomic absorption spectroscopy (AAS) after methylisobutlyketone (MIBK) extraction. Details of this method have already been described (Homer and Dooley, 1983). Concentrations were calculated against an organotin standard (Chemplex Spectrostandard) prepared (weight per volume) in HIBK.

Single samples from selected leach rate determinations were also analyzed by hydride reduction coupled with AAS detection to determine the distribution of organotin in the leachate as the tributyl-, dibutyl-, and monobutyltin species. The technique is based on the method originally described by Hodge, Seidel, and Goldberg (1979). Optimization of the method for analysis of tributyltin has been described by Valkirs, Vafa, Seligman, Lieberman, and Stang (1985).

LEACH RATE CALCULATIONS

The organotin emission rate (leach rate) was calculated from the increase in tin measured in the system as a function of time. The total tin in the system at each sampling time was calculated by multiplying the total volume of the system by the concentration of tin determined by AAS. The volume of water within each system varied by as much as 200 ml, depending on how much water was expelled when the initial vacuum was established. Consequently, calibration curves were generated for each system to relate the observate vacuum gauge reading to the volume of water expelled (Figure 5). This permits accurate determination of the total volume of the system for each determination. Reported leach rate values for each paint system were obtained by pooling the data from the three domes at each sample site. The slope from the regression of the pooled data set of tin versus time was used to calculate the leach rate.

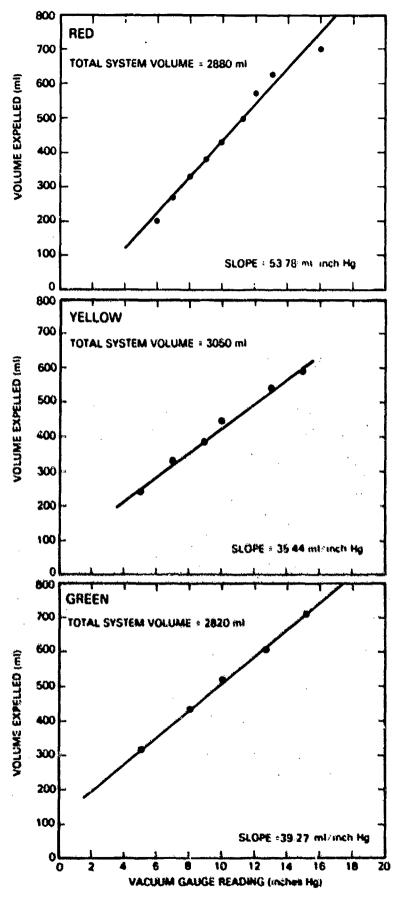


Figure 5. Calibration curves of volume of seawater expelled from dome versus measured vacuum.

The code for the basic program used to generate the plots of tin versus time and to calculate leach rate values and the 95-percent confidence limits of the estimate is listed in Appendix A. A representative plot of tin versus time for a pooled data set is shown in Figure 6. Individual plots of tin versus time for the three domes at the same sampling location often produced different y-intercepts even though the slopes were similar (e.g., Figures 7a, 7b, and 7c). Consequently, all data were normalized to a y-intercept of zero prior to pooling the data from any sample location.

Differences in initial concentrations for different domes may depend on how much the slime layer on the paint surface is disturbed when the dome is placed on the hull. Disturbance of the slime layer is suggested by the fact that the sample collected at time T=0 often showed somewhat elevated tin concentrations. Consequently, the first sample was not included in the regression analyses. Because the leach rate depends only on the rate of increase of tin within the closed system over time, differences in the initial concentration within the system do not affect the final result. This is illustrated in Figures 7a, 7b, and 7c where the three determinations showed different initial concentrations but similar slopes. Comparisons showed the mean leach rate calculated from three separate determinations at each sample site was nearly identical to that obtained by pooling the normalized data. The pooled data, however, permits a better statistical estimate of the overall variability of each determination. Reported values are expressed in terms of the 95-percent confidence limits calculated from the confidence limits on the regression coefficient of the pooled data (Sokal and Rohlf, 1969).

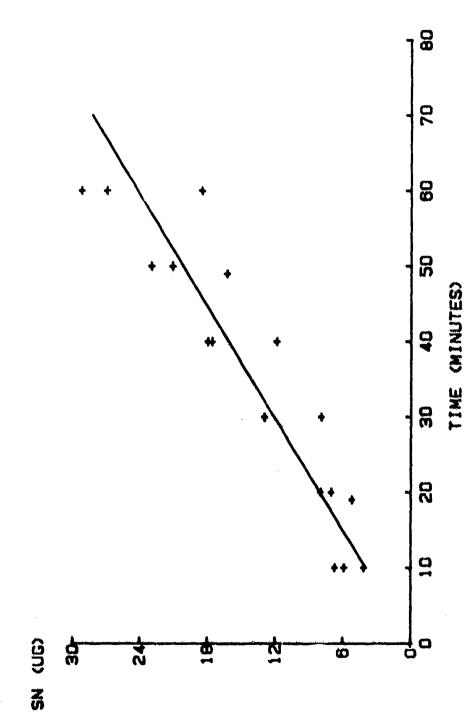
ANCILLARY MEASUREMENTS

Temperature and pH were also measured near each ship hull using a Horiba Model U-7 Water Quality Checker equipped with a cable that permitted the sensor to be lowered to a maximum depth of 10 m. Manufacturer's specifications state the measurement precision for the instrument is ± 0.1 pH units and ± 0.5 degrees Centigrade. In seawater, the accuracy of the pH measurement is probably not much better than ± 0.2 pH units because of problems associated with standardization in a high-ionic strength medium.

STATION: A/POOLED DATA DATE: 14 AUG 84 PAINT SYSTEM, OMP M5211F SHIP, USS MEYERKORD

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Figure 6. Plot of tin versus time for the UMP M5211F paint system on the USS MEYERKORD (pooled data set).

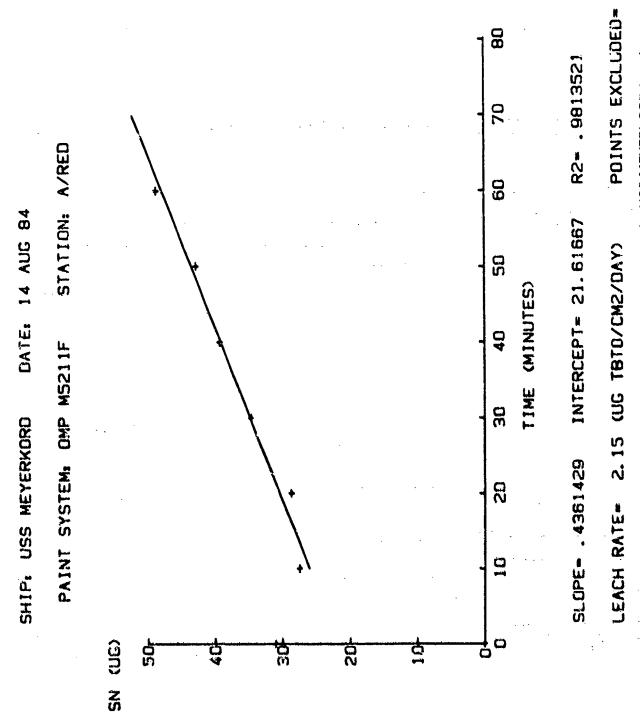


Figure 7a. Plot of tin versus time for the OMP M5211F paint system on the USS MEYERKORD (red dome system).

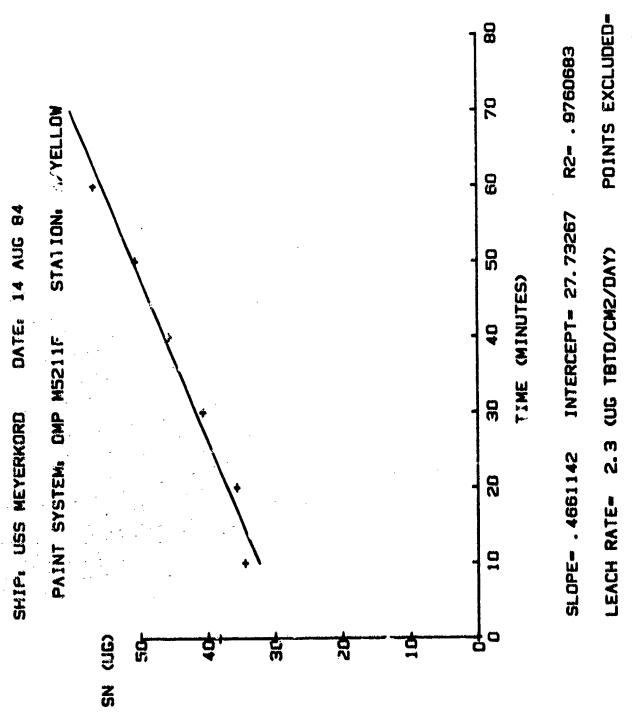


Figure 7b. Plot of tin versus time for the OMP M5211F paint system on the USS MEYERKORD (yellow dome system).

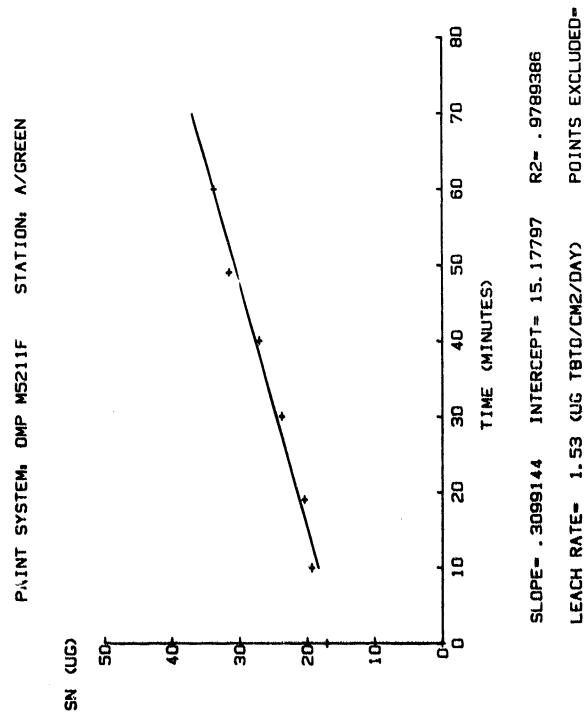


Figure 7c. Plot of tin versus time for the OMP M5211F paint system on the USS MEYERKORD (green dome system).

RESULTS AND DISCUSSION

Table 1 summarizes the results of in situ leach rate measurements conducted in Norfolk on the USS CORAL SEA (CV 43) and the USS BIRMINGHAM (SSN 695) during July 1984, in Long Beach on the USS MEYERKORD (FF 1050) during August 1984, and in San Diego on the MEYERKORD during December 1984. Except where noted, reported values are the result of normalizing and pooling the data from three separate determinations at each sample site. Values are expressed in terms of the 95-percent confidence limit of the estimate. Plots of individual determinations from each dome and plots of the pooled data set for each paint system are presented in Appendix B. Table 1 shows the measured leach rates ranged from a low of 0.18 to a high of 3.2 μ g/cm²/day. The SPC-254 coating on the CORAL SEA showed the lowest leach rate with a mean value of 0.24+0.05 μ g/cm²/day for the five areas investigated. The OMP M5211S coating on the MEYERKORD showed the highest value. Note, however, the value for the OMP M5211S paint system does not appear to be significantly different from the other OMP systems or the ABC-2 coating on the BIRMINGHAM.

Laboratory studies have shown that the leach rate of certain paint systems is a function of pH and temperature (Adema and Jackson, 1982). Considerable differences in pH and temperature were observed in the ambient water where these measurements were conducted. The pH ranged from a low of 7.4 in the brackish waters of Norfolk Naval Shipyard to a high of 8.4 in the warm saline waters of Long Beach Naval Shipyard. Measurements conducted in San Diego Bay in December on the MEYERKORD were done at intermediate pH values and relatively low ambient temperatures. Based on the limited set of data presented here, observed differences in leach rates (e.g., measurements conducted on the same paint systems on the MEYERKORD during August in Long Beach and during December in San Diego) could not be solely related to pH and temperature effects. The authors believe that part of the reason no clear trends are evident with regard to pH and temperature differences is that under environmental settings the micro environment created by the slime layer on the hull may actually regulate the pH in the vicinity of the hull-water interface. In addition, the ship's movement from Long Beach to San Diego may have altered the slime layer on the paint surface and caused variances in the measured leach rates. The authors plan to continue to document the pH and temperature of the ambient water as more measurements are made to attempt to resolve the effect of environmental differences in pH and temperature on leach rates for different paint systems.

Based on the measurements made to date, the in situ leach rate technique used in this study appears to provide an accurate, reliable method for determining organotin release rates from ship hulls under realistic environmental conditions. Inspection of the individual plots of tin versus time (three of which are presented in Figures 7a, 7b, and 7c) shows the increase in tin concentration is, in general, highly linear between 10 and 60 minutes with R² values of greater than 0.95 in 28 of the 33 measurements made in July and August of 1984. Although no direct comparisons were made on a single panel, laboratory measurements made to confirm the greater than expected values for the ABC-2 paint system (Table 2) produced results similar to those obtained using the in situ system.

Table 1. Summary of in situ leach rate determinations of several organotin antifouling coatings.

Ship/Date	Paint System	Depth (ft)	Leach Rate* (µgTBT/cm ² /day)	Temp (deg C)	рН
MEYERKORD/Aug 84	ABC-2	3	0.80+21%	24.1	8.4
MEYERKORD/Aug 84	ABC-2	9	0.70+7%	23.8	8.4
MEYERKORD/Dec 84	ABC-2	6	0.33+26	16.0	7.8
BIRMINGHAM/Jul 84	ABC-2	10	2.3+314	NR	NR
MEYERKORD/Aug 84	OMP M5211F	3	2.0+22%	24.1	8.4
MEYERKORD/Dec 84	OMP M5211F	6	1.6+124	16.0	7.8
MEYERKORD/Aug 84	OMP M5211S	3	2.4+284	24.1	8.4
MEYERKORD/Dec 84	OMP M5211S	6	3.2+21 4	16.0	7.8
MEYERKORD/Aug 84	OMP 58S	3	1.7+18%	24.1	8.4
MEYERKORD/Dec 84	OMP 58S	6	0.72+44	16.0	7.8
MEYERKORD/Aug 84	SPC-4	3	0.40+24%	24.1	8.4
MEYERKORD/Dec 84	SPC-4	6	1.7+229	16.0	7.8
CORAL SEA/Jul 84	SPC254	15	0.31+444	26.2	7.5
CORAL SEA/Jul 84	SPC-254	5	0.28+22	26.4	7.5
CORAL SEA/Jul 84	SPC-254	10	0.21+20	26.3	7.5
CORAL SEA/Jul 84	SPC-254	5	0.18+154	26.4	7.5
CORAL SEA/Jul 84	SPC-254	5	0.22+319#1	26.4	7.5

^{* + 95%} confidence limit

NR not recorded

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[•] value based on measurements from only one system

[#] value based on measurements from only two systems

slime layer removed

Table 2. Summary of in situ and laboratory-determined leach rates for ABC-2 antifouling coating.

		Leach Rate*	Temp			
Method	Ship/Panel	(gTBT/cm ² /day)	(deg C)	рн		
In situ - USS	MEYERKORD					
	Aug 1984	0.80+20%	24.1	8.4		
	Aug 1984	0.70+7%	24.1	8.4		
	Dec 1984	0.33+26%	16.0	7.8		
In situ - USS	BIRMINGHAM					
	July 1984	2.3+31*	NR	NR		
Laboratory - USS KITTY HAWK						
	Aug 1984	3.3 <u>+</u> 148#	22	8.3		
	Dec 1984	1.7+19%	17	NR		
Laboratory - 8	San Diego Bay	2.8 <u>+4</u> 0\$	21	8.0		

 ^{+95%} confidence limits

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An attempt was made to determine whether removal of the slime layer before the dome was placed on the hull made a significant difference in the rate of toxicant release from the hull of the CORN. SEA. Because of time constraints and other shippard activities, only one set of samples was collected with the slime layer removed. Results suggest that removal of the slime layer did not change the leach rate determined for the 3-month-old AF system.

Results of hydride-AAS determinations of the monobutyl-, dibutyl-, and tributyltin in the leachate are presented in Table 3. Although the results must be considered preliminary because of the limited number of samples analyzed to date, there appears to be a significant difference in the quantity of dibutyltin present in the leachate from the different paint systems. Measurements of the ABC-2 paint system on the MEYERKORD and on a test panel show the dibutyltin component ranged from 13 to 38 percent with a mean of 28 percent for the eight samples measured. In contrast, leachates from the SPC and OMP paint systems did not contain any measurable quantities of di- or monobutyltin. It is not clear at present whether these differences represent a dibutyltin impurity in the ABC-2 paint or some difference in the degradation of the tributyltin for the different paint systems. Because leach rates were calculated assuming all tin extracted by MIBK was in the form of tributyltin, hydride measurements indicated that ABC-2 values may be overestimated by an amount up to the fraction of tin present as dibutyltin. These results demonstrate why organotin speciation information is important to properly evaluating the behavior of these compounds in the environment.

NR not recorded

[#] value based on measurements from only two systems

Table 3. Percent monobutyl-, dibutyl- and tributyltin in leachate determined by the hydride-AAS technique.

		DBT		Total Sn
Paint System/Ship or Panel	MBT	(percent)	TBT	(µg/L)
ABC-2/MEYERKORD (Aug 84)	NM	38	62	5.4
	NM	38	62	4.6
	NM	34	66	6.8
	NM	35	65	8.6
	nm	13	87	7.7
	ИМ	19	81	5.7
ABC-2/Panel	NM	18	84	9.7
	МИ	26	74	5.0
SPC 254/CORAL SEA (July 84)	мм	NM	100	1.8
	им	NM	100	3.8
OMP M58S/MEYERKORD (Aug 84)	NM	NM	100	6.3
	NM	NM	100	6.6
	МИ	NM	100	6.9

NM = below detection limit of 0.01 μ g/L

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 Speciation of butyltins and methyltins in segwater and marine sediments by hydride derivatization and atomic absorption detection. (NOSC Tech. Rep. 1037) San Diego: Naval Ocean Systems Center.

APPENDIX A BASIC PROGRAM FOR PLOTTING AND CALCULATING LEACH RATE DATA

```
10 KEM PROGRAM TINPLOT
20 REM
          THIS PROGRAM PLOTS TIN LEACH RATE DATA FROM NON-DOCUMENT
               FILES CREATED WITH WORDSTAR, THE DATA IS THEN REGRESSED, THE LEACH RATE IS CALCULATED AND THE 95% CONFIDENCE
30 REM
40 REM
               LIMITS OF THE ESTIMATE IS CALCULATED FROM THE CONFIDENCE
50 REM
               LIMITS OF THE REGRESSION COEFFICIENT
60 REM
70 REM
80 REM
        GRAPHICS COMANDS FOR PLOTTING THE DATA ARE FOR A HP7470A PLOTTER
90 REM
         PROGRAM REVISED 11 JAN 85
100 REM
                                        S.H.LIEBERMAN
110 REM
120 OPEN "COM1:9600,N,7,1" AS #1
130 INPUT "INPUT NAME OF FILE CONTAINING DATA (EG., B:TINDATA) "
140 OPEN "I", #2,F$
150 REM OPEN COMMUNICATION PORT BETWEEN COMPAG AND PLOTTER
160 INPUT #2,5$,P$,SY$,D$
170 PRINT $$,P$,SY$,D$
180 REM OPEN FILE CONTAINING LEACH RATE DATA
                                                              ",YMIN,YMAX
190 INPUT "INPUT YMIN AND YMAX FOR PLOT (EG., YMIN, YMAX)
200 INPUT "INPUT NUMBER OF INITIAL POINTS TO SKIP FOR REGRESSION ", NS
210 PRINT #1, "IN;"
220 PRINT W1;"DT"CHR$(3)
230 PRINT W1; "V8;"
240 REM DRAW AND LABEL AXES ON PLOT
250 PRINT #1, "SM;"
260 PRINT W1,"IP1200,1800,7400,5500;SP1;"
270 PRINT #1, "SCO, 80, "YMIN, YMAX";"
280 PRINT #1,"TL1.5,0;"
290 PRINT W1,"SI.19,.27;"
300 PRINT #1."PAO,"YMIN";"
310 FOR X=0 TO 80 STEP 10
320 PRINT Mi, "PD;"
330 FOR J=1 TO 200: NEXT J
340 PRINT W1, "PD;PA", X, YMIN";PU;XT;"
350 IF X>=10 THEN 380
360 PRINT W1,"CP-1.33,-1;"
370 IF X<=9 THEN 390
380 PRINT W1,"CP-1.835,-1;"
390 PRINT #1."LB";X;CHR#(3)
400 PRINT #1," ;PA",X,YMIN";"
410 NEXT X
420 PRINT #1,"TL1,"YMIN";"
430 PRINT #1, "PAO, "YMIN ";"
440 Sm(YMAX-YMIN)/5
450 FOR YEYMIN TO YMAX STEP S
460 PRINT #1, "PD:PAO,",Y,":PU:YT:"
470 IF Y>=100 THEN PRINT H1, "CP-3.57, ... 25; "100TO 500
480 IF Y>=10 THEN PRINT NI, "CP-2.9,-.25;":GUTO 500
490 PRINTHI, "CP-2.23,-.25;"
SOO PRINT W1, "LB":YICHR6(3)
SIG FOR JOL TO 300 (NEXT J
520 PRINT 81, " :PAG.",Y
530 NEXT Y
340 PRINT WI, "PAO,"YMAX";CP-6,1.5:"
550 PRINT 81, "LBSN (UG)")CHR$(3)
S66 PRINT M1: "PAO, "YMAX"; CP60,8;"
570 PRINT 01, "LBFILEN "FFSICHR#(3)
L TX38 .0001 OT Let ANY OBC
SVO PRINT WI, "PAO, "YMAX" PEPP, 61" NOO PRINT WI, "LBSHIP: "; S$:"
                                    DATE: ":D$; CHR$(3)
610 FOR Jal TO 3000: NEXT J
620 PRINT N1, "PAO,"YMAX";CP4,4;"
630 PRINT N1, "LBPAINT SYSTEM; ";P6;"
                                             STATION: ":S/#;CHR#(3)
30 FOR JET IN 3000: NEXT J
```

```
650 PRINT #1, "PA40,"YMIN";CF-8,-2.5;"
660 PRINT #1, "LBTIME (MINUTES)"; CHR$(3)
670 INPUT"FINISHED WITH AXES "STRIKE ANY KEY TO CONTINUE", Z$
680 PRINT #1, "LTO;"
690 PRINT #1, "SM+;"
700 REM PLOT DATA
710 ON ERROR GOTO 800
720 INPUT #2,X,Y
730 PRINT "Y=",Y
740 PRINT #1, "PA";X;Y;"PD"
750 FOR J=1 TO 200; NEXT J
760 GOTO 720
770 PRINT "RETURNING TO CLOSE FILE"
780 CLOSE #2
790 FRINT #1, "PU:PAO, "YMIN";"
800 PRINT ERR
810 IF ERR=62 THEN RESUME 770
820 ON ERROR GOTO O
830 REM REGRESSION ROUTINE
840 PRINT "REGRESS DATA"
850 OPEN "I", #2,F$
860 ON ERROR GOTO 1510
870 N::0
880 AX:40
890 AY=0
900 SXS=0
910 SYS=0
920 SSX=0
930 SSY"0
940 N=0
950 SX#0
960 8400
970 SXY=0
980 INPUTH2 .S.P. P.SY.D.
990 INPUTM2, X,Y
1000 REM CALCULATE N. SUM OF X(SX). SUM OF Y(SY)
                    THE SUM OF X AND SUM OF Y SQUARED (SXS) (SYS)
1010 REM
                              " XY (SXY)
1020 REM
1030 N#N+1
1040 IF N<9NS GOTO 990
1050 PRINT X.Y
1060 SX0SX+X
1070 SY#SY+Y
1080 SXS#SXS+X^2
1090 SYB=SYS+Y^2
1100 SXY=SXY+(X*Y)
1110 GOTO 990
1120 REM CALCULATE AVRG.OF X(AX) AND UF Y (AY)
                    SQUARE OF THE SUM OF X AND OF Y . (SSA). (SSY)
1130 REM
1140 N=N-HS
1150 PRINT "N=".n,"SX=".SX-"SY=".SY-".SX5=".SX5-"SY5=".SY5."SXY=".SXY
1160 AX"SX/N
1170 AYSYYN
1180 9SX#SX^2
1190 SSY#SY^2
1200 A=SYS-(SY*2/H)
1210 B#SXS (SX^2/N)
1220 C=SXY~((SX*SY)/N)
1230 REM CALCULATE 95% CONFIDENCE LIMITS
1240 SE#SURCCCA~CCC×C)/B))/(N-2))/B)
1250 IF N-2m17 THEN TOIST#2.11
1260 IF N-2=16 THEN TOIST=2.12
1270 IF N-2=15 THEN TOIST=2.131
1280 IF N-2014 THEN TOIST 2.145
1290 IF N-2:13 THEN TDIST=2.16
1300 IF N=2*12 THEN TPIST+2.179
```

```
1310 IF N-2=11 THEN TDIST-2.201
1320 IF N-2::10 THEN TOUST -2.228
1330 IF N=2=9 THEN TDIST=2.262
1340 IF N-2-8 THEN TD1ST-2.306
1350 IF N-2-7 THEN TD1ST-2.365
1360 IF N-2:18 THEN TOTST 2.101
1370 IF N-2=6 THEN TDIST=2.447
1380 IF N-2#5 THEN TDIST: 2.571
1390 IF N-2=4 THEN TDIST=2.776
1400 IF N-2=3 THEN TDIST=3.182
1410 IF N-2=2 THEN TDIST=4.303
1420 CL=TDIST*SE
1430 PRINT ""
1440 PRINT ""
1450 SLOPE=((N*SXY)-(SX*SY))/((N*SXS)-SSX)
1460 INTERCEPT=(SY-(SLOPE*SX))/N
1470 R#((N*GXY)~(SX*SY))/(((SXS*N)~SSX)*((N*S\S)~SSY))^.5
1480 R2=R^2
1490 PRINT "SLOPE=".SLOPE, "INTRCEPT=".INTERCEPT. "Re".R. "R2=".R2
1500 CLOSEN2
1510 PRINT ERR
1520 IF ERROG2 THEN RESUME 1120
1530 ON ERROR GOTO O
1540 PRINT N1, "LT;"
1550 PRINT N1, "SN;"
1560 FOR X=10 TO 70 STEP 10
1570 Y=(SLOPE*X)+INTERCEPT
1580 PRINT W1. "PA".X.Y":PD:"
1590 NEXT X
1600 PRINT N1, "PU:PAO."YMIN":"
1610 PRINT N1, "CP2:-5:"
1620 PRINT N1, "LBSLOPE: ":SLOPE:" INTERCEPT:":INTERCEPT:" R2%":R2:CHR4-
1830 BEN CALCULATE LEACH RATE
1640 REM LRESLOPE (ug/min) & 60(min/hr) & 24(hr/dmy) & 1/729.7(cm^2) & 2.50 % "
Ozug Sn)
1650 LR-SLOPE+60+24+2.5/729.7
1460 PCL CL/SLOPE
1670 LRCL*PCL*LR
1880 PURCL CINT (FROLM R* 199)
1890 PRINT "LEACH RATE CONFIDENCE LIMITS" - PURCL
1700 LRIMINTORE
1/10 RE*(CINT((LR-LRI)*100))/100
1990 TROUBLARE
1730 PEINT LR
1740 PRINT WI. "PUIPAG." (MIN")
1770 PRINT WI. "PUIPAG. "YM!#"."
1,200 END
```

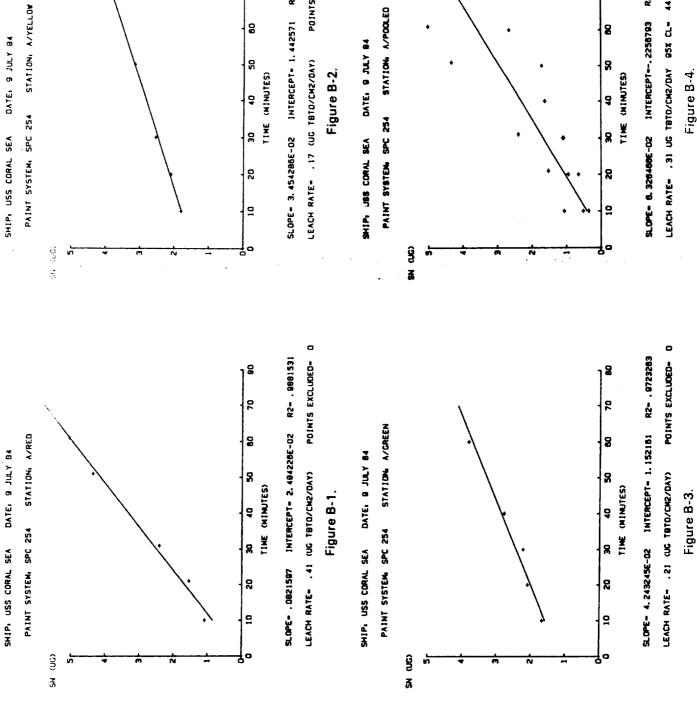
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PLOTS OF TIN VERSUS TIME FOR INDIVIDUAL LEACH RATE DETERMINATIONS AND FOR POOLED DATA

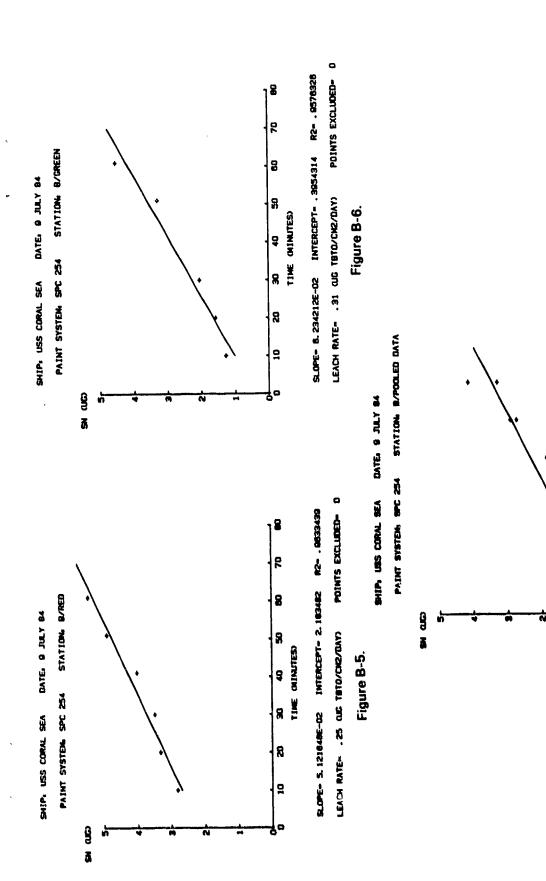
Figure	Ship	Paint	Dome	Survey Date
B-1	Coral Sea	SPC 254	Red	7-9-84
B-2	•	•	Yellow	#
B-3	•	**	Green	•
B-4	w	•	Pooled	#
B-5	CORAL SEA	SPC 254	Red	7-9-84
B-6	•	•	Green	w
B-7	•	•	Pooled	•
B-8	CORAL SEA	SPC 254	Red	7-10-84
B-9	**	•	Green	•
B-10		•	Pooled	w
B-11	CORAL SEA	SPC 254	Red*	7-10-84
B-12	•	•	Yellow	
B-13	•	•	Green	*
B-14	•	•	Pooled	•
B-15	CORAL SEA	SPC 254	Redt	7-10-84
B-16		•	Green*	•
B-17	•	v	Pooled	•
B-18	B IRM INGHAM	ABC-2	Re₫	7-11-84
B-19	•	•	Yellow	•
B-20	•	•	Green	•
B-21	•	•	Pooled	•
B-22	MEYER KORD	ABC-2	Red	8-14-84
B-23		•	Yellow	•
B-24	•	•	Green	•
B-25	•	, ₩	Pooled	•
B-26	MEYER KORD	ABC-2	Red	8-15-84
B-27	•	•	Yellow	•
B-28	•	•	Green	•
B-29	•	•	Pooled	•
B-30	MEYERKORD	OMP 58S	Red	8-14-84
B-31	•	•	Yellow	•
B-32	•	•	Green	•
B-33	•	•	Pooled	•
B-34	MEYER KORD	SPC-4	Red	8-14-84
B-35	•	•	Yellow	*
B-36	•	•	Green	•
B-37	•	•	Pooled	•
B-38	MEYERKORD	OMP M5211F	Red	8-14-84
B-39		.⊎	Yellow	•
B-40	•	•	Green	•
B-41	•	•	Pooled	•
B-42	MEYERKORD	ONP 5211S	Red	8-15-84
B-43	•	•	Yellow	•
B-44	•	•	Green	
B-45	•	•	Pooled	•
B-46	MEYER KÖRD	ABC-2	Red	12-11-84
B-47	•	•	Yellow	•
8-48	•	•	Green	•
B-49	•	•	Pooled	•

^{*}Slime layer removed

Figure	Ship	Paint	Dome	Survey Date
B-50	MEYERKORD	OMP 5211F	Red	12-11-84
B-51	•	•	Yellow	•
B-52	•	w	Green	•
B-53	•		Pooled	•
B-54	MEYERKORD	OMP 5211S	Red	12-11 -84
B-55	•	•	Yellow	•
B-56	•		Green	*
B-57	•	•	Pooled	*
B-58	MEYER KORD	SFC-4	Red	12-12-84
B-59	•	•	Yellow	•
B-60	•	•	Green	
B-61	•	*	Pooled	•
B-62	MEYERKORD	OMP 58S	Red	12-12-84



LEACH RATE. , 31 UG TBTO/CM2/DAY 95% CL- 44 % POINTS EXCLUDED" 0 POINTS EXCLUDED- 0 SLOPE- 3, 454286E-02 INTERCEPT- 1, 442571 R2- , 9942681 SLOPE- 6. 326460E-02 INTERCEPT ... 2256793 R2- . 6693645 2 PAINT SYSTEM SPC 254 STATION A/POOLED 8 SHIP, USS CORAL SEA DATE, 9 JULY 84 LEACH RATE . 17 (UG TBTD/CM2/DAY) TIME (MINUTES) Figure B-2. Figure B-4. TIME CHINUTES 9 39



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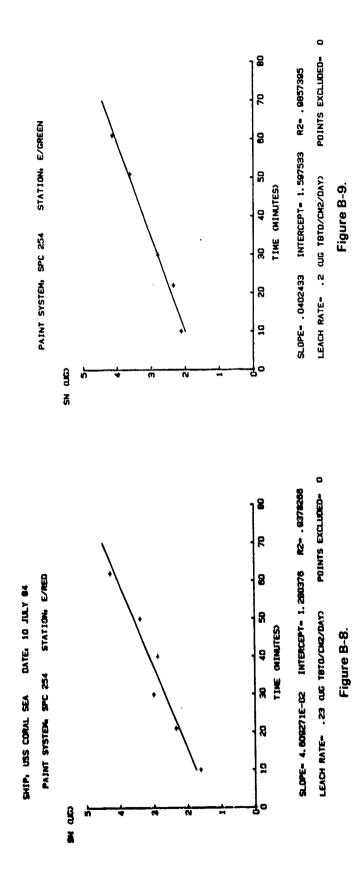
91.0PE= 5.841003E-02 INTENCEPT--8.019301E-03 R2- .9203802 LEACH RATE- .29 UG T810/CH2/DAY 85X CL- 22 X POINTS EXCLUDED- 0

Figure B-7.

2

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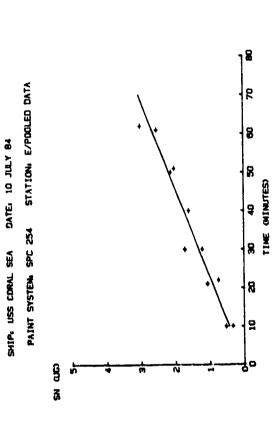
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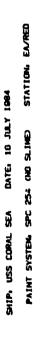


LEACH RATE. . 21 UG TBTD/CKZ/DAY 85% CL. 19 % POINTS EXCLUDED.

Figure B-10.

SLOPE. 4, 333677E-02 INTERCEPT. 3, 445018E-03 R2- , 9376179

B-6



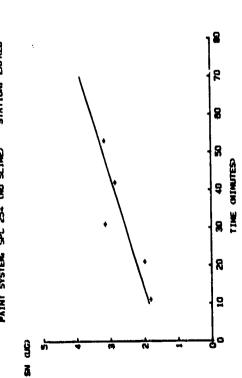
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DATE: 10 JULY 84

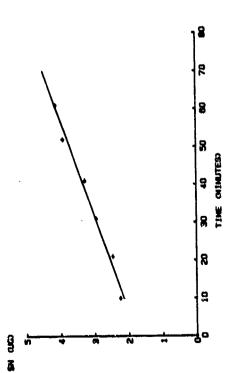
SHIP, USS CORAL SEA



8LOPE- 3.335213E-G2 INTERCEPT- 1.538073 R2- .7448887 LEACH RATE- .18 GG TETO/CHZ/DAY) PDINTS EXCLUDED- '0

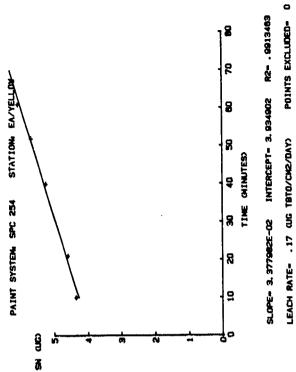
Figure B-11.

SHIP, 55 CORAL SEA DATE, 10 JULY 1984 PAINT SYSTEM SPC 254 STATION EA/GREEN

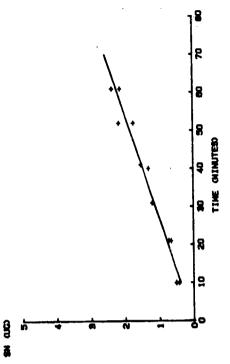


SLOPE- 2. 923037E-02 INTERCEPT- 1.75104 R2- . 0837253 LEACH RATE- . 18 CLG 1810/CHZ/DAY) POINTS EXCLUDED- 0

Figure B-13.

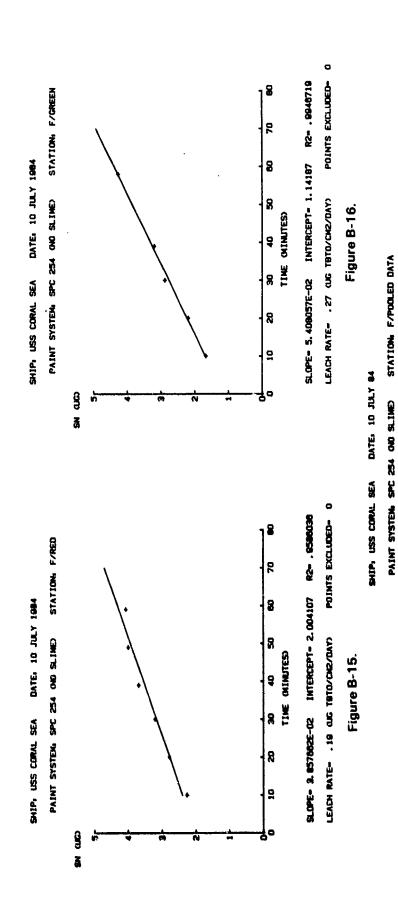


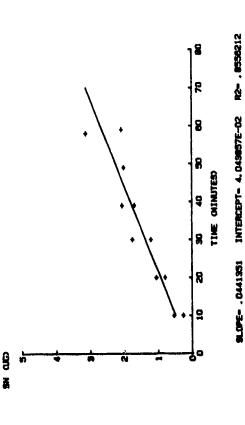
LEACH RATE- . 17 QUG TBTQ/CMZ/DAY) POINTS EXCLUDED-FIGURE B-12.
SHIP, USS CORAL SEA DATE, 10 JULY 84
PAINT SYSTEM, SPC 254 STATION, EA/POOLED DATA



SELPFE- 1. 641607E-02 INTERCEPT- 1. 906110E-02 N2- . 0611226 LEACH RATE- . 18 UG TBTD/DIZ/DAY 95% CL- 15 % POINTS EXCLUDED- 0

Figure B-14.

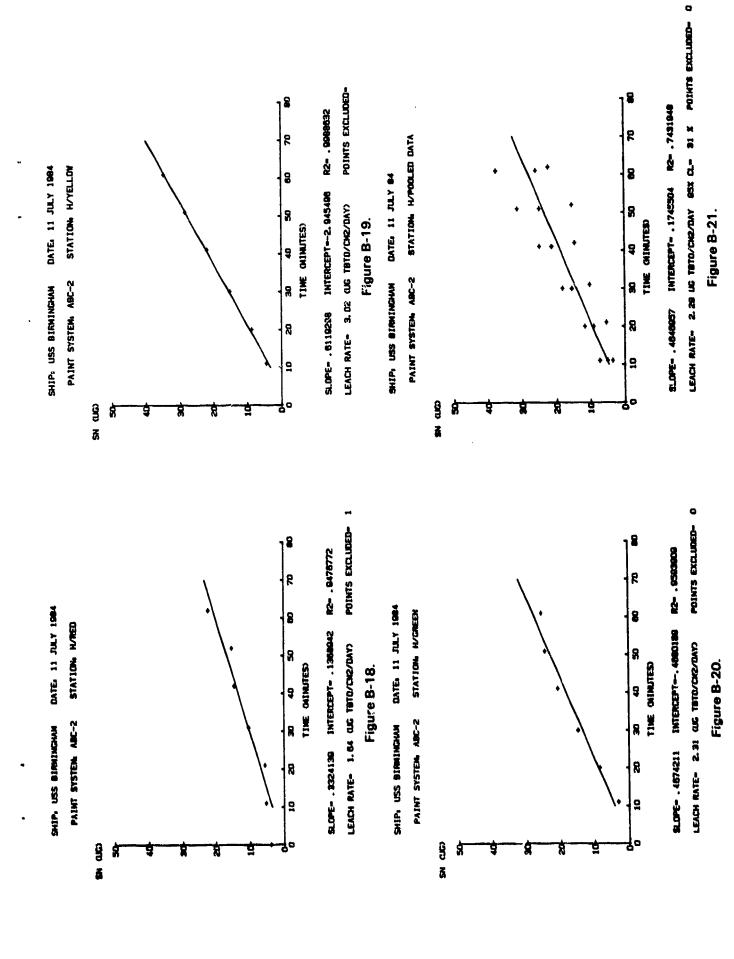




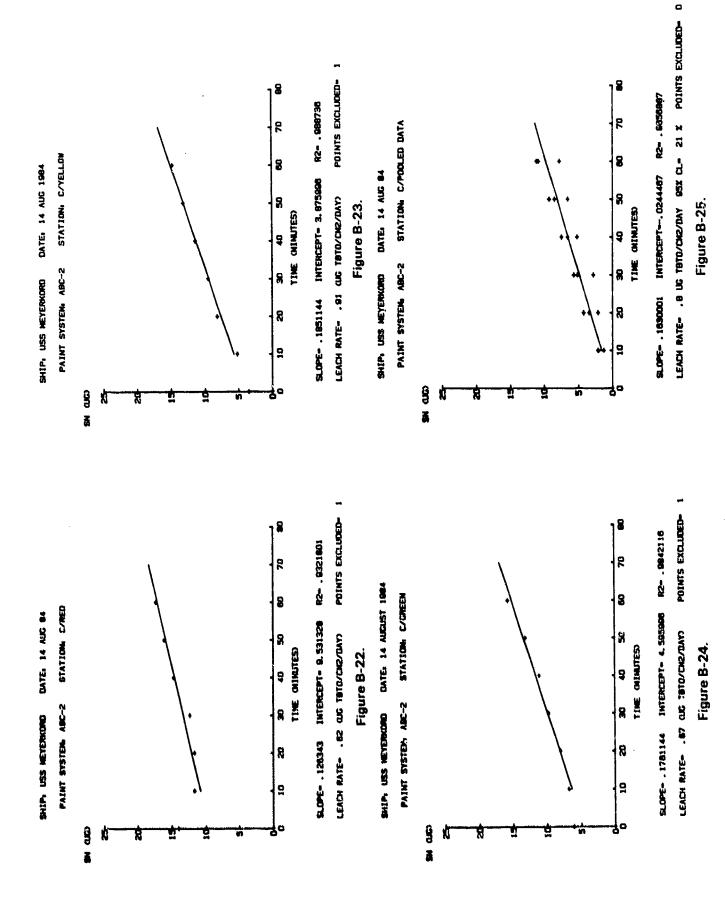
LEACH RATE- . 22 UG TBTD/CH2/DAY 95% CL- 31 % POINTS EXCLUDED- 0

Figure B-17.

B-8

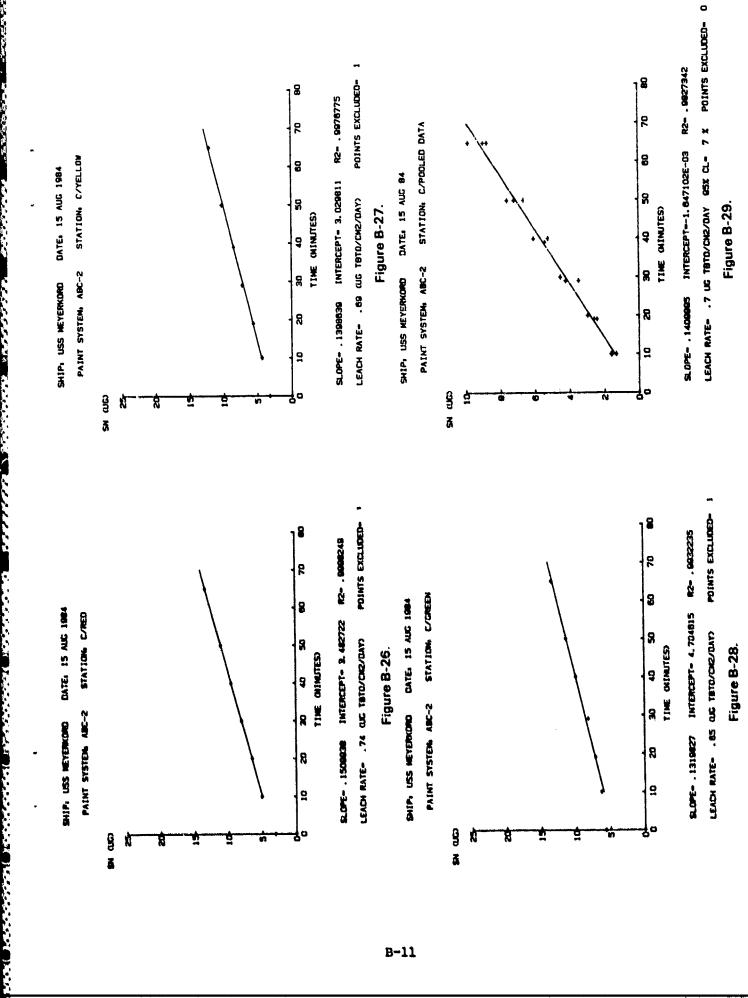


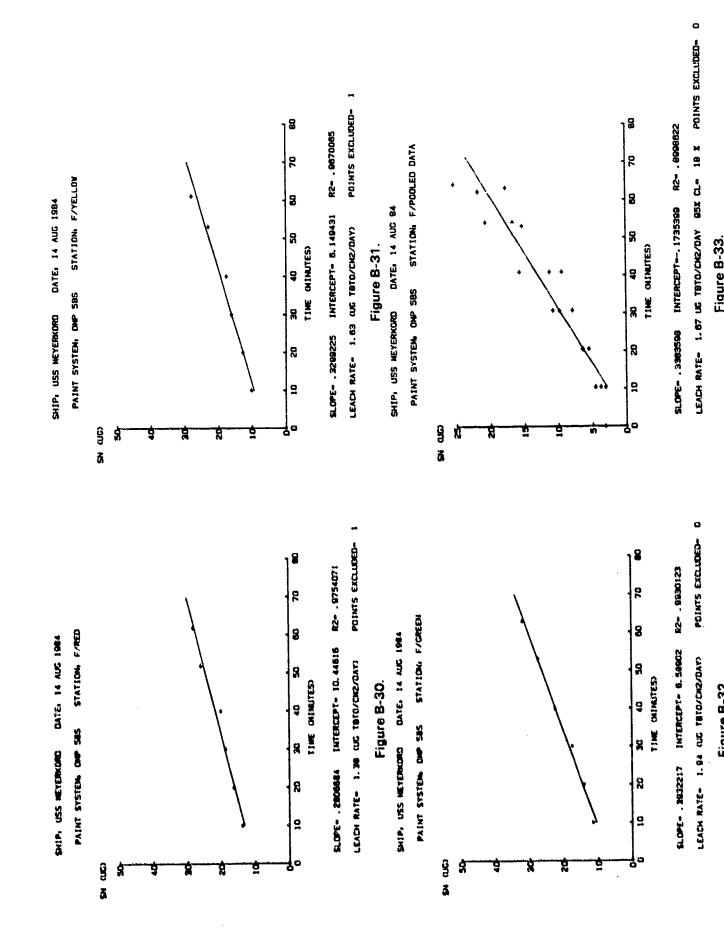
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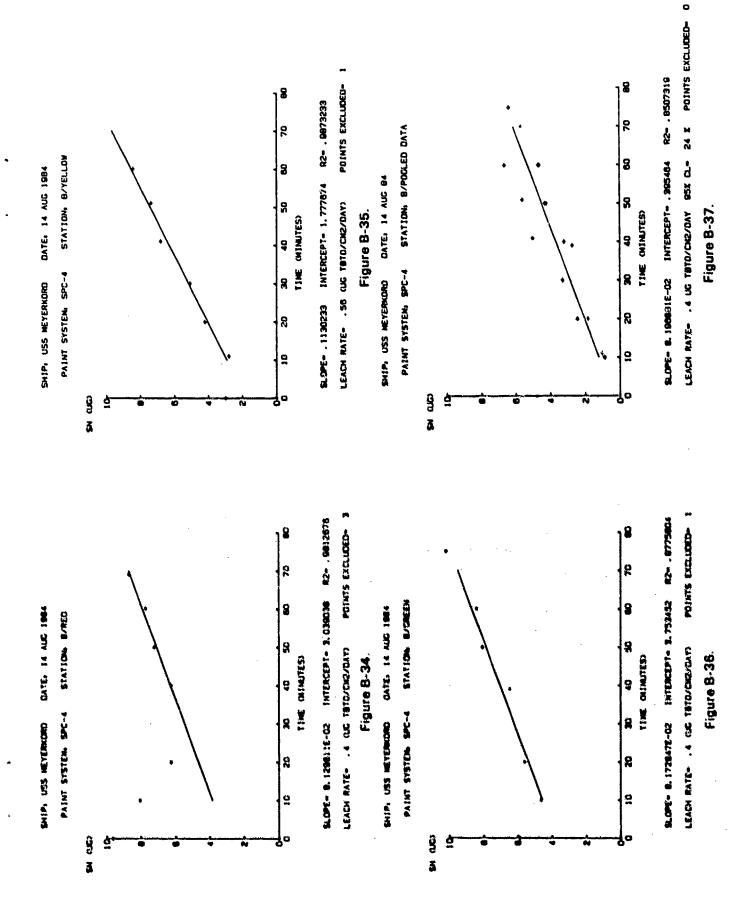


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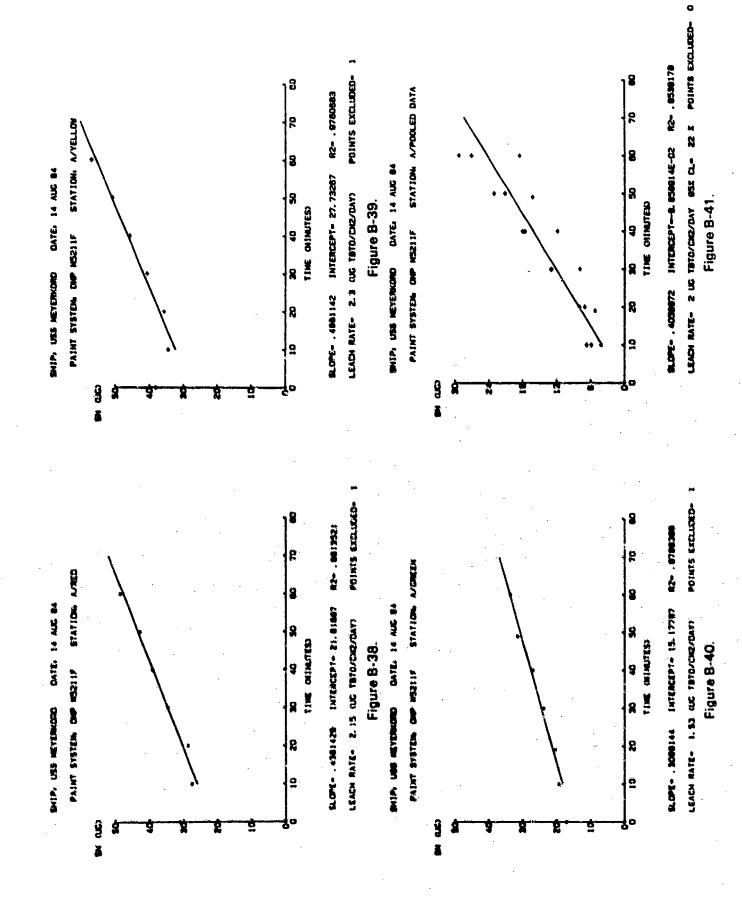
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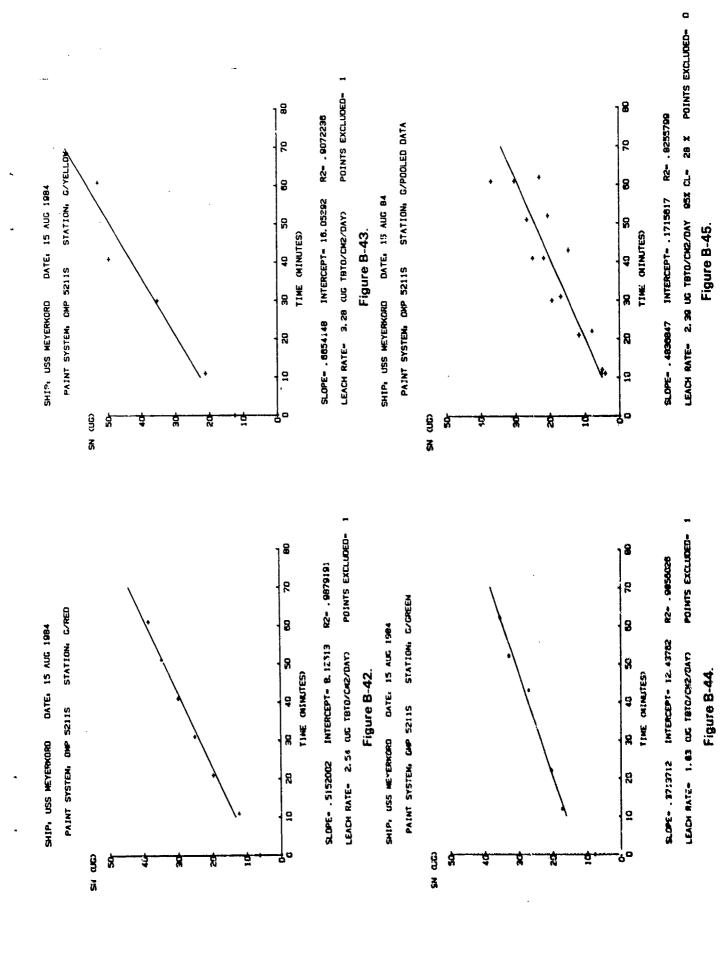


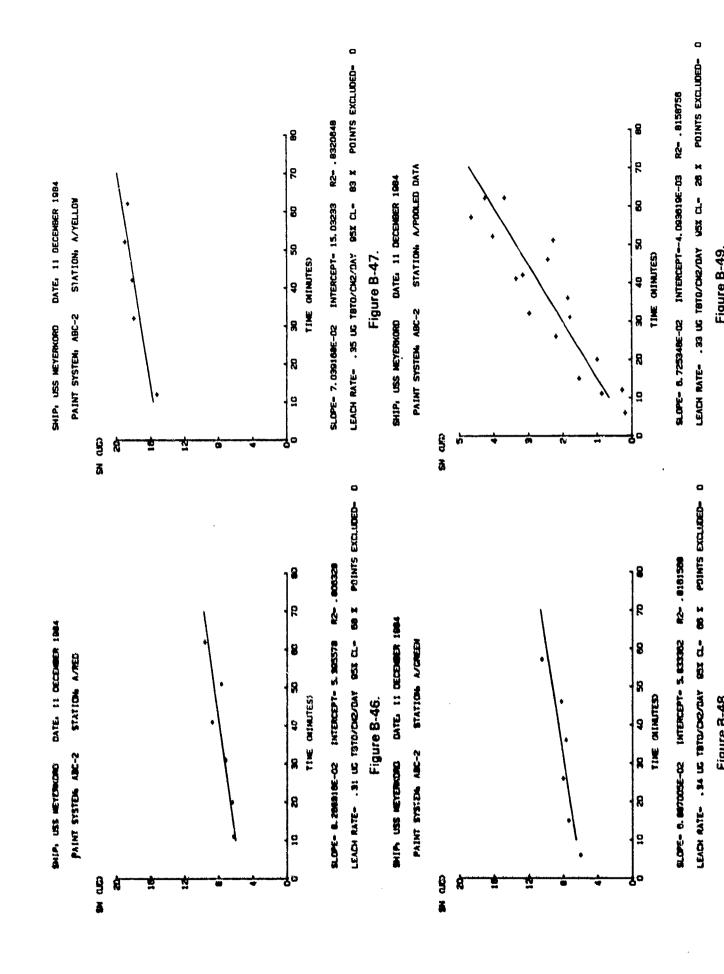




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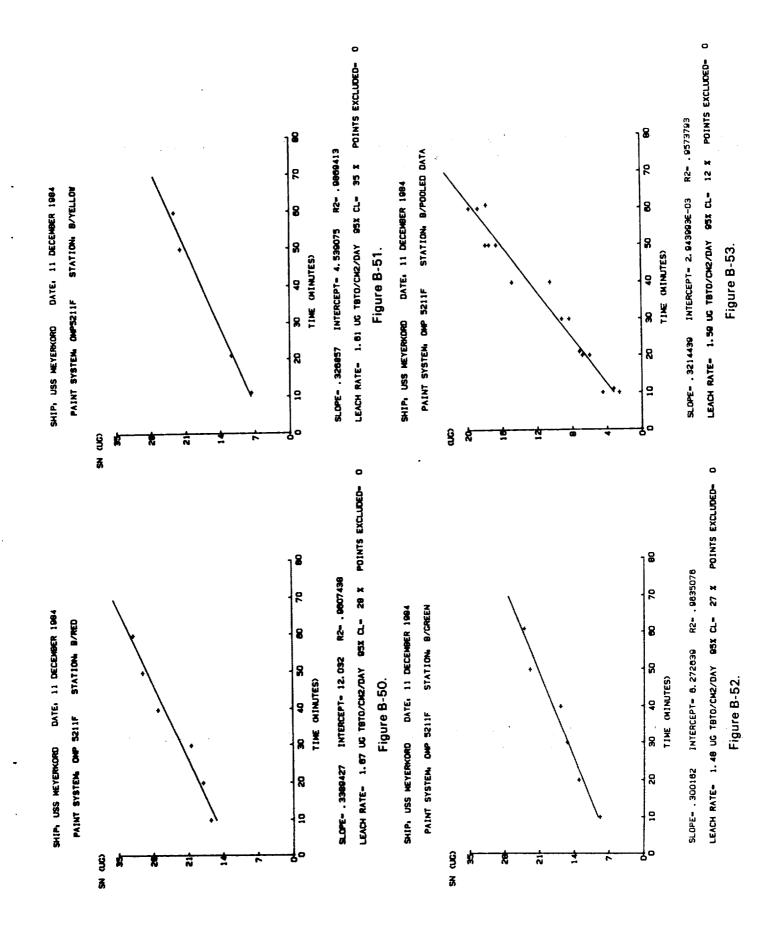


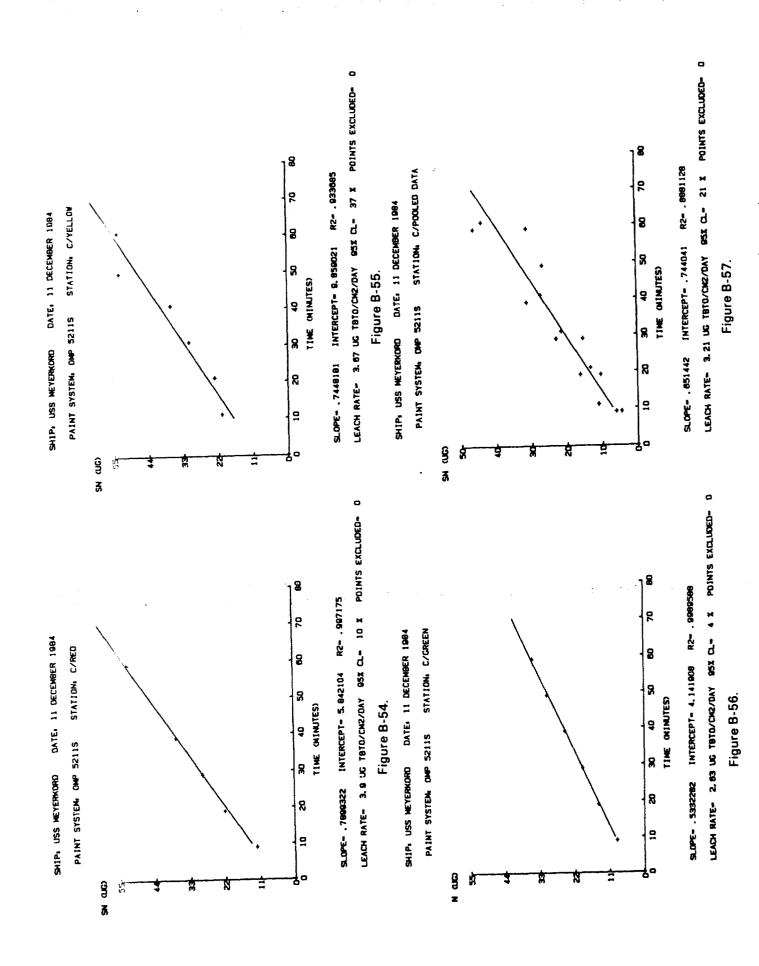


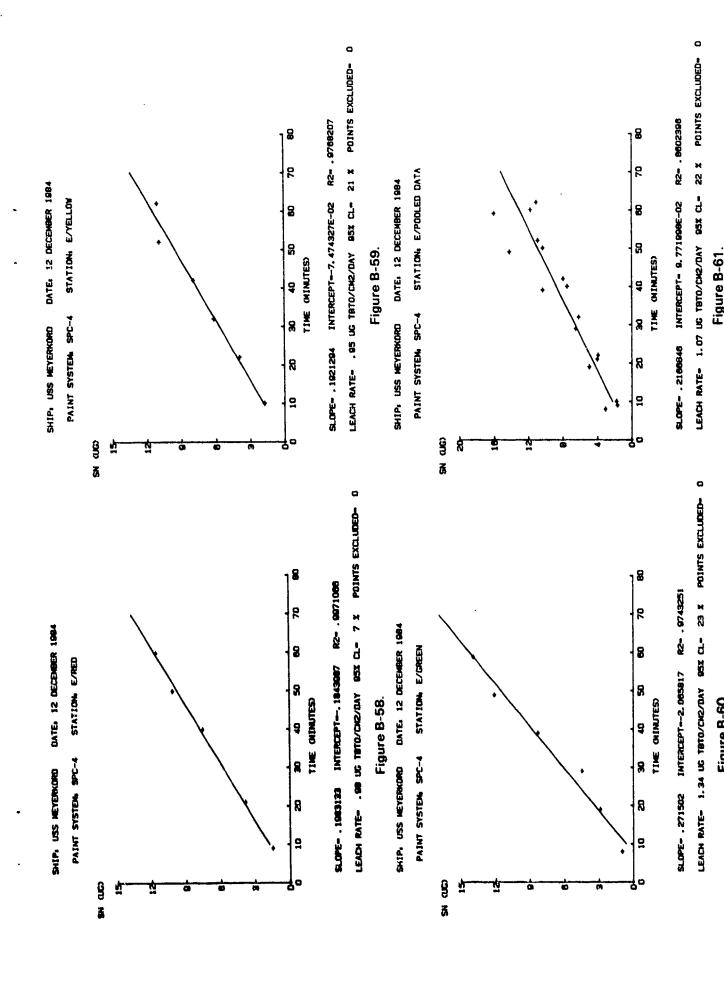


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B-16



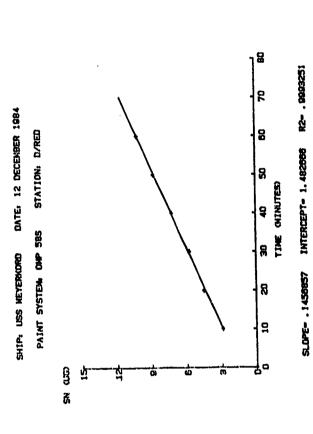




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LEACH RATE- .72 UG TBTD/CHZ/DAY 85% CL- 4 % POINTS EXCLUDED-

Figure B-62.

B-20

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